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Dynamic Wireless Charging of Electric Vehicles Using Induction Coupling with Selective Coil Activation

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Abstract

Electric vehicles are increasingly adopted as a sustainable alternative to conventional transportation, but cable-based charging still creates operational limitations related to manual connection, connector wear, safety, and charging downtime. This paper presents a prototype dynamic wireless charging system for electric vehicles based on inductive coupling and selective coil activation. The proposed system uses multiple transmitter coils arranged along a charging track, a receiver coil mounted on the vehicle side, an Arduino Uno controller, infrared sensors for vehicle-position detection, relay-based coil switching, a zero-voltage-switching driver, and a rectifier-filter receiver circuit. Instead of energizing all transmitter coils continuously, the controller activates only the coil located below the receiver. This selective activation approach reduces unnecessary power consumption, decreases heat generation, and supports automatic contactless charging. Experimental prototype observations confirm successful wireless power transfer, stable receiver-side DC output for LED and DC motor loads, reliable sensor-controlled switching, and improved output when transmitter and receiver coils are properly aligned. The results also show that coil misalignment, increased air gap, relay delay, and sensor sensitivity are key limitations requiring further improvement before large-scale roadway deployment. The proposed system demonstrates a low-cost and practical foundation for smart electric vehicle charging infrastructure and dynamic charging roads.

Index Terms—Dynamic wireless charging, electric vehicles, inductive coupling, selective coil activation, wireless power transfer, Arduino, IR sensor, ZVS driver.

I. INTRODUCTION

The growth of electric vehicles (EVs) has created a strong demand for charging systems that are safe, convenient, automatic, and suitable for public transportation infrastructure. Conventional plug-in charging requires physical connectors, manual user intervention, and stationary charging time. These requirements create practical issues in public stations, outdoor environments, and high-use mobility systems. Cable wear, connector damage, exposure to moisture, and difficulty in frequent plug-in operation make conventional charging less attractive for future smart transportation systems [1], [2].

Wireless power transfer (WPT) provides an alternative approach by transferring electrical energy through electromagnetic fields rather than direct conductive contact. In inductive coupling, an alternating current in the transmitter coil produces a time-varying magnetic field, which induces voltage in a nearby receiver coil. This principle is suitable for short-distance EV charging because it can provide contactless energy transfer with simple coil structures and reduced mechanical wear [3], [4].

Dynamic wireless charging extends the WPT concept by allowing a vehicle to charge while moving over a prepared track or road segment. In such systems, transmitter coils may be placed under the road surface and a receiver coil is mounted on the vehicle. However, if every transmitter coil remains ON continuously, large standby losses, excessive heat, and unnecessary electromagnetic field exposure may occur. Therefore, selective coil activation is introduced to energize only the transmitter coil located under the moving receiver section.

This paper presents a hardware prototype for dynamic wireless EV charging using induction coupling with selective coil activation. The prototype combines a multi-coil transmitter track, IR sensor-based position detection, Arduino-based control, relay switching, a ZVS driver, a receiver coil, bridge rectifier, filter capacitor, and DC load. The main objective is to demonstrate automated power transfer and compare the practical behavior of selective activation with continuous coil activation at prototype level.

The major contributions of this work are: 1) design of a low-cost dynamic wireless charging prototype using readily available components; 2) implementation of sensor-based selective coil activation for reducing unnecessary energization; 3) integration of a high-frequency ZVS driver with transmitter and receiver coils; and 4) experimental observation of alignment, air-gap, and switching effects on prototype operation.

II. RELATED WORK

Power electronic converters, grid-connected renewable systems, and EV charging stations have been widely studied for improving the reliability and efficiency of modern transportation energy systems. Solar and hybrid renewable energy charging systems have been proposed for EV applications, including V2G/G2V power exchange and stand-alone PV-wind EV charging configurations [1], [2]. Converter control methods for bidirectional energy exchange and EV charging applications have also been investigated [3], [5].

Grid synchronization, converter control, and power quality are important for integrating charging infrastructure into renewable and smart-grid environments. Reviews on distributed generation control, improved AC–DC converters, DSTATCOM control, and grid converters show the need for stable power conversion and reliable control in modern charging systems [4], [6]–[8]. In EV-focused smart grids, scheduling and vehicle integration studies further highlight the importance of automated charging and energy management [9], [10].

For wireless charging, resonant inductive power transfer has received attention because it can improve transfer performance when transmitter and receiver circuits operate near resonance. Current-fed and resonant inductive charging approaches have been studied for EV battery charging, showing the feasibility of contactless charging architectures [11]. The present work differs from static wireless charging by focusing on a segmented transmitter track, vehicle-position sensing, and selective activation of transmitter coils during movement.

III. PROPOSED SYSTEM

The proposed system consists of two main sections: transmitter and receiver. The transmitter section includes a DC power supply, ZVS driver, relay module, multiple transmitter coils, Arduino Uno controller, and IR sensors. The receiver section includes a receiver coil, bridge rectifier, filter capacitor, and output load such as an LED or DC motor. The transmitter coils are arranged along a short track to represent a dynamic charging road segment.

The operating sequence is as follows. First, the DC supply is given to the transmitter-side circuit. The IR sensor detects the position of the moving receiver module. The Arduino reads the sensor output and turns ON the corresponding relay channel. The relay energizes only the transmitter coil directly below the receiver. The ZVS driver converts the DC input into high-frequency AC, which excites the active transmitter coil. The alternating magnetic field links with the receiver coil and induces AC voltage. The receiver-side rectifier and filter capacitor convert the induced AC voltage into DC output for the connected load.

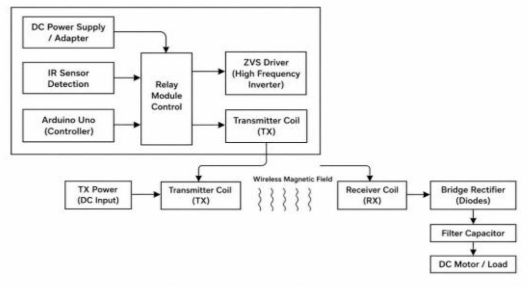

Fig. 1. Block diagram of the proposed dynamic wireless charging system.

The selective activation logic is the central control feature of the prototype. If no vehicle is present above a given transmitter section, the corresponding coil remains OFF. When the receiver reaches a sensor zone, the controller activates that coil and deactivates previously active coils. This operation reduces standby power loss and avoids energizing unused transmitter sections.

IV. HARDWARE DESIGN AND METHODOLOGY

A. Transmitter-Side Design

The transmitter side is responsible for generating the high-frequency magnetic field required for inductive power transfer. A ZVS driver is used to achieve efficient high-frequency switching with reduced switching loss and heat. The transmitter coils are connected through relay contacts, so the controller can select which coil should receive excitation from the driver. The relay module provides electrical isolation between the low-power Arduino control circuit and the higher-power transmitter circuit.

Four transmitter coils are arranged on the track in the prototype. Each coil corresponds to one sensor detection zone. When the vehicle enters a zone, the relay channel associated with that coil closes and the coil becomes active. This segmented transmitter arrangement represents the basic concept of a dynamic charging lane.

B. Receiver-Side Design

The receiver coil is placed on the vehicle module and receives power from the active transmitter coil through magnetic coupling. The induced voltage is AC, so a bridge rectifier is used to convert it into DC. A 500 μF filter capacitor smooths the rectified output. The resulting DC voltage is applied to small prototype loads such as an LED and DC motor to verify successful energy transfer.

C. Sensor and Controller Design

IR sensors are used for position detection because they provide a simple and low-cost method for identifying the receiver location. Sensor outputs are connected to the Arduino Uno. Based on the active sensor input, the Arduino sends a control signal to the appropriate relay. The control algorithm follows a one-coil-at-a-time activation strategy so that only the transmitter coil under the receiver remains energized.

D. Basic Inductive Coupling Principle

The induced voltage in the receiver coil follows Faraday's law. If N is the number of receiver coil turns and Φ is the magnetic flux linking the coil, the induced voltage is expressed as
$e = -N (d\Phi/dt)$.

The output voltage and load performance depend mainly on coil alignment, air gap, coupling coefficient, operating frequency, and the quality of the resonant network. The practical testing in this work therefore focuses on aligned, misaligned, and larger air-gap conditions.

V. IMPLEMENTATION

The implementation was carried out using an Arduino Uno, IR sensor modules, a 4-channel relay module, a ZVS driver, transmitter coils, a receiver coil, bridge rectifier, 500 μF filter capacitor, 0.01 μF tuning capacitor, 1 kΩ resistor, LED indicator, 12 V battery, and DC load. The circuit was assembled so that the sensing and control path remained separated from the transmitter power path through relay switching.

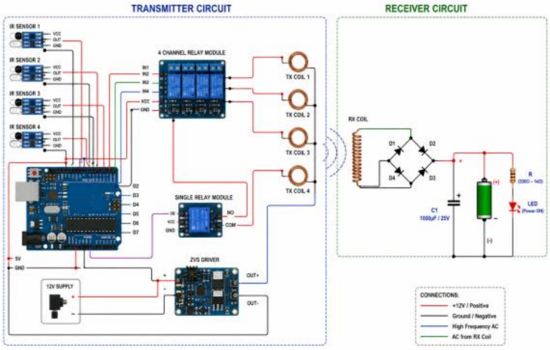

Fig. 2. Transmitter and receiver circuit arrangement used in the prototype.

The transmitter coils were placed along the track, and IR sensors were mounted near each coil position. The relay module was connected between the ZVS driver output path and the transmitter coils. The receiver coil was attached to a small vehicle platform to emulate a moving EV receiver. During testing, the receiver was moved over the coil track and the corresponding coil was activated automatically.

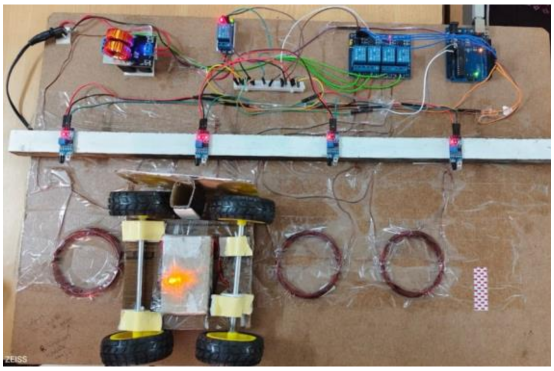

Fig. 3. Working model output during receiver movement above the transmitter track.

VI. RESULTS AND DISCUSSION

The prototype successfully demonstrated wireless power transfer using inductive coupling and selective coil activation. The receiver side generated sufficient DC output to operate the connected LED and DC motor loads. The system remained stable during repeated testing and operated automatically without manual switching. The observations also confirmed that selective activation reduced unnecessary energization of unused coils compared with continuous coil operation.

Table I. Prototype performance observations

- Proper alignment: bright LED illumination, smooth DC motor operation, and stable DC output due to strong magnetic coupling.
- Receiver misalignment: reduced LED brightness, lower motor speed, and gradual voltage drop due to weaker mutual coupling.
- Increased air gap: weak power transfer and low induced voltage because coupling decreases with distance.
- Selective coil activation: only the coil below the receiver is energized, reducing standby loss and improving power utilization.
- Relay-based transition: a small switching delay is observed because of electromechanical relay response.

Under proper alignment, the receiver coil was positioned directly above the active transmitter coil. In this case, stronger magnetic coupling occurred and the output load performance improved. The LED brightness increased and the DC motor operated smoothly. Under misalignment, the received voltage reduced because less magnetic flux linked with the receiver coil. Under larger air gap, power transfer became weak because the coupling between transmitter and receiver coils decreased.

The comparison between continuous and selective activation is important for dynamic charging systems. In continuous activation, all transmitter coils remain ON even when the receiver is above only one coil. This increases power consumption and heat generation. In the proposed selective method, only the required coil is activated based on sensor detection. Therefore, the method is more suitable for smart roads where many transmitter sections may be installed along a charging lane.

VII. ADVANTAGES, LIMITATIONS, AND APPLICATIONS

A. Advantages

The proposed system provides contactless energy transfer and eliminates the need for charging cables. It reduces mechanical wear, improves user convenience, and supports automatic operation. Selective coil activation prevents continuous operation of all transmitter coils, reducing unnecessary power consumption and heat generation. The sensor-based control architecture also makes the system suitable for smart EV infrastructure.

B. Limitations

The prototype has several practical limitations. First, efficient charging requires accurate alignment between transmitter and receiver coils. Second, the output decreases as the air gap increases. Third, relay switching creates a small operational delay during coil transition. Fourth, IR sensors may produce inconsistent readings under certain lighting conditions. Finally, the prototype transfer range is limited and prolonged operation may cause heat in the transmitter coils and driver circuit.

C. Applications

The system can be applied in EV charging stations, dynamic wireless charging roads, automated parking systems, smart transportation infrastructure, industrial automation, public transport charging systems, and small consumer wireless charging applications. At larger scale, the same principle can support bus lanes, fleet charging corridors, automated guided vehicles, and smart-city EV infrastructure.

VIII. CONCLUSION AND FUTURE SCOPE

This paper presented the design and implementation of a dynamic wireless charging prototype for electric vehicles using inductive coupling with selective coil activation. The system successfully transferred power from the transmitter side to the receiver side without direct physical contact. An Arduino Uno, IR sensors, and relay module were used to detect the receiver position and activate only the required transmitter coil. The ZVS driver generated the high-frequency AC needed for inductive transfer, while the receiver coil, rectifier, and filter capacitor produced usable DC output for LED and DC motor loads.

The experimental observations confirmed that proper alignment and reduced air gap are critical for better output performance. The selective activation approach reduced unnecessary coil operation compared with continuous activation and demonstrated a practical path toward efficient dynamic EV charging. Future work should include high-power semiconductor switching instead of electromechanical relays, closed-loop voltage and current control, quantitative efficiency measurement, improved coil geometry, electromagnetic shielding, multi-receiver testing, weatherproof roadway packaging, and integration with renewable energy and grid-connected storage systems.

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